

Intense look at Virgo Southern Extension

I. D. Karachentsev^{1*}, O. G. Nasonova^{1†}

¹*Special Astrophysical Observatory of the Russian Academy of Sciences, Nizhnij Arkhyz, KChR, 369167, Russia*

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ABSTRACT

We collected data on radial velocities and distances of galaxies to elucidate structure and kinematics of the filament attached to the Virgo cluster from south. In the region $RA = [12.5 - 13.5]^h$, $Dec = [-20 - 0]^\circ$ there are 171 galaxies with radial velocities $V_{LG} < 2000 \text{ km s}^{-1}$, and 98 of them have distance estimates. This galaxy cloud, called as “Virgo Southern Extension”, is situated just on the edge of the Virgo “zero-velocity surface”. The mean distance to Virgo SEx, $17 \pm 2 \text{ Mpc}$, and the average radial velocity, $1172 \pm 23 \text{ km s}^{-1}$, are very close to the Virgo cluster ones. In Supergalactic coordinates the Virgo SEx dimensions are $15 \times 7 \times 2 \text{ Mpc}$, where the major axis is directed along the line of sight, the second-major axis looks towards the Virgo core and the minor one is perpendicular to the Supergalactic plane. This flattened cloud consists of a dozen virialized groups with the total K -band luminosity of $1.7 \cdot 10^{12} L_\odot$ and the total virial mass of $6.3 \cdot 10^{13} M_\odot$, having a typical dark matter-to-stellar matter ratio of 37. The Hubble diagram for Virgo SEx galaxies exhibits a tendency of Z -shape wave with a velocity amplitude of $\sim 250 \text{ km s}^{-1}$ that may be caused by a mass overdensity of $\sim 6 \cdot 10^{13} M_\odot$, and in order of magnitude agrees with the sum of virial masses of the groups.

Key words: galaxies: distances and redshifts, (cosmology:) large-scale structure of Universe

1 INTRODUCTION

The virial mass estimates for groups and clusters of galaxies in the Local Universe within $\sim 50 \text{ Mpc}$ result in the average matter density $\Omega_m \simeq 0.06 - 0.10$ (Vennik 1984, Tully 1987,

* E-mail: ikar@sao.ru

† E-mail: phiruzi@gmail.com

(Magtesian 1988, Makarov & Karachentsev 2011), which is 3–4 times less than the global value $\Omega_m \simeq 0.25 - 0.30$ (Spergel et al. 2007). Several possible explanations of this discrepancy were regarded in the overview of (Karachentsev 2012). The “missing dark matter” paradox can be sourced by the presence of extended dark “suburbs” distributed mainly outside the virial radii of groups and clusters of galaxies (Tavio et al. 2008, Masaki et al. 2011, Chernin et al. 2012). Some authors suggest that the hidden dark matter is concentrated in dark filaments and bridges between clusters (Dinshaw et al. 1997, Impey et al. 1999, Rosenberg et al. 2003). The first observational evidence of their existence has appeared recently (Dietrich et al. 2012).

The Virgo cluster of galaxies situated at a distance of 16.5 Mpc (Mei et al. 2007) is the nearest cluster with an angular diameter of the virial core $\sim 12^\circ$. It provides a unique possibility to search for dark matter structures. Karachentsev et al. (2011, 2012) discussed the kinematics of two regions: Coma I and Ursa Majoris, extending north from the Virgo cluster along the Supergalactic equator. The UMa region has turned to be an association of common groups with the normal virial mass-to-luminosity ratio. However, the observed “Z-wave” disturbance of the Hubble flow in the Coma I region possibly points out the existence of a dark attractor with the mass of $\sim 1 \cdot 10^{14} M_\odot$ situated 15 Mpc from us.

It is well known that bright galaxies are concentrated along the Supergalactic equator not only northward of the Virgo cluster but also southward (de Vaucouleurs & de Vaucouleurs 1973). Tully (1982) has called this structure “Virgo Southern Extension”. According to Tully (1982), Virgo SEx is characterized by dimensions of $\Delta SGX \simeq \Delta SGY \simeq 10$ Mpc and $\Delta SGZ \simeq 4$ Mpc, bordering directly on the virial core of the Virgo cluster. Virgo SEx occupies approximately a region of sky given by $RA = [12.0^h - 13.5^h]$, $Dec = [+5^\circ, -20^\circ]$, while the radial velocities of galaxies populating it belong to the interval $[500 < V_{LG} < 1700]$ km s^{−1}. The Virgo SEx location proposed by Tully seems to be rather conventional. Other authors (Binggeli et al. 1993, Yoon et al. 2012) limited the Virgo Southern Extension by the interval $Dec \simeq [0, +5^\circ]$. Considering the distance estimates for 22 galaxies in the Virgo SEx area, Tully & Shaya (1984) inferred that this filament guides galaxy flow into the virial zone of the Virgo cluster. Yoon et al. (2012) examined the absorption L $_{\alpha}$ -lines in spectra of 7 quasars situated behind the Virgo SEx and suggested the existence of a large-scale flow of warm intergalactic gas towards the cluster centre.

It is worth emphasizing that structure and kinematics of the Virgo Southern Extension

lack for researchers' application until recently. The accumulated observational data allow now to investigate this complex of galaxies in more detail.

2 STRUCTURE OF THE VIRGO SOUTHERN EXTENSION REGION

Optical and HI surveys carried out recently have improved significantly the observational basis for analysis of Virgo SEx structure. We restricted our consideration to the sky region with equatorial coordinates $RA = [12^h30^m - 13^h30^m]$, $Dec = [-20^\circ, 0^\circ]$ and to the radial velocities relative to the Local Group centroid $V_{LG} < 2000 \text{ km s}^{-1}$. According to the catalogue of nearby galaxy groups (Makarov & Karachentsev 2011) there is about a dozen groups in this area with corresponding velocities. A list of 171 galaxies in the Virgo SEx zone with $V_{LG} < 2000 \text{ km s}^{-1}$ is represented in Table 1. It includes several galaxies outside the mentioned area which belong to the groups with centres lying inside the region. The columns of the table contain: (1) galaxy name in known catalogues; (2) its equatorial coordinates at the epoch J2000.0; (3) radial velocity in the LG reference frame; the main sources of velocity data are LEDA (<http://leda.univ-lyon1.fr>) and NED (<http://ned.ipac.caltech.edu>) databases; (4) morphological type on the de Vaucouleurs scale; most types were determined by us independently of other sources; (5) apparent magnitude of a galaxy in the K_s -band from 2MASS survey (Jarrett et al. 2000); the 2MASS lacks K_s -data for many blue and diffuse galaxies, so in these cases we make estimates for K_s -magnitude from B -magnitude and mean colour index $< B - K >$ for galaxies of each morphological type according to procedure described by Jarrett et al. (2000); (6) name of the dominating galaxy of a group according to Makarov & Karachentsev (2011); (7,8) distance modulus and corresponding distance (in Mpc); distance estimates are taken from NED favouring most recent data (Tully et al. 2009; Springob et al. 2009); in more than half the instances we estimated (M-m)-moduli ourself via Tully-Fisher relation using data on apparent magnitudes B_T and HI line widths W_{50} ; (9) method applied for estimating distance: “tf” – from Tully-Fisher relation, “sbf” – from surface brightness fluctuations (Tonry et al. 2001), “SN” – from Supernovae luminosity, “mem” – from galaxy membership in a group with measured distance.

Galaxy distribution in the Virgo SEx region is represented in Fig. 1 with circles. Large circles mark most bright galaxies with apparent magnitudes $K_s < 9.0^m$. In the upper panel of the figure galaxies of early, intermediate and late morphological types are shown with different colours. The solid line corresponds to the Supergalactic equator. In the lower panel

of the figure colours distinguish galaxies in different velocity ranges, while group members are linked with dominating galaxies by straight lines.

The total distribution of galaxy number over radial velocities for Virgo SEx complex is shown in Fig. 2; the galaxies with prevailing bulge component ($T < 3$) are greyed.

According to this data the distribution of galaxies over the sky seems to be clumpy and extended along the Supergalactic equator. The mean radial velocity and the mean morphological type of galaxies are actually independent on galaxies' distance from the Virgo centre. The total distribution of Virgo SEx galaxies over radial velocities follows in good agreement the Gaussian shape with the mean $\langle V_{LG} \rangle = +1172 \text{ km s}^{-1}$ and the standard deviation $\sigma_v = 285 \text{ km s}^{-1}$. For galaxies with prominent bulges these values are 1106 km s^{-1} and 282 km s^{-1} , respectively. The observed distribution $N(V_{LG})$ differs significantly from a strictly increasing one predicted by a uniform distribution of galaxies in the space. In other words, the filamentary structure of Virgo SEx can be considered as a kinematically segregated formation.

Some specific features of the sky region under investigation should be noted. It follows from the data by Tully & Shaya (1984) and Karachentsev & Nasonova (2010) that the radius of the zero velocity surface around the Virgo cluster is $R_0 \simeq 6.5 \text{ Mpc}$ or $\sim 23^\circ$. Therefore, the southern boundary of the accretion sphere passes just through the centre of the Virgo SEx complex along the line of $Dec \simeq -10^\circ$. Alternatively, the Virgo SEx area is situated not far from the Great Attractor direction, so the kinematics of the considered sample of galaxies can be influenced by this aggregate. Unfortunately the zone which includes the Virgo SEx region is not represented photometrically in the CGCG (Zwicky et al. 1961–1968) and ESO (Lauberts & Valentijn 1985) catalogues. Even some bright galaxies populating this area have therefore a certain disagreement in their apparent magnitude estimates to an extent of 2^m – 3^m . However, a part of considered region is already covered with SDSS data (Abazajian et al. 2009) and, moreover, this structure is located completely in the HIPASS survey zone (Zwaan et al. 2003, Meyer et al. 2004).

3 HUBBLE FLOW IN THE VIRGO SOUTHERN EXTENSION COMPLEX

The velocity-distance relation for 98 galaxies in the Virgo SEx zone is represented in the upper panel of Fig. 3. The straight line corresponds to the unperturbed Hubble flow with the parameter $H_0 = 73 \text{ km s}^{-1} \text{ Mpc}^{-1}$. Isolated galaxies are shown as crosses while the members

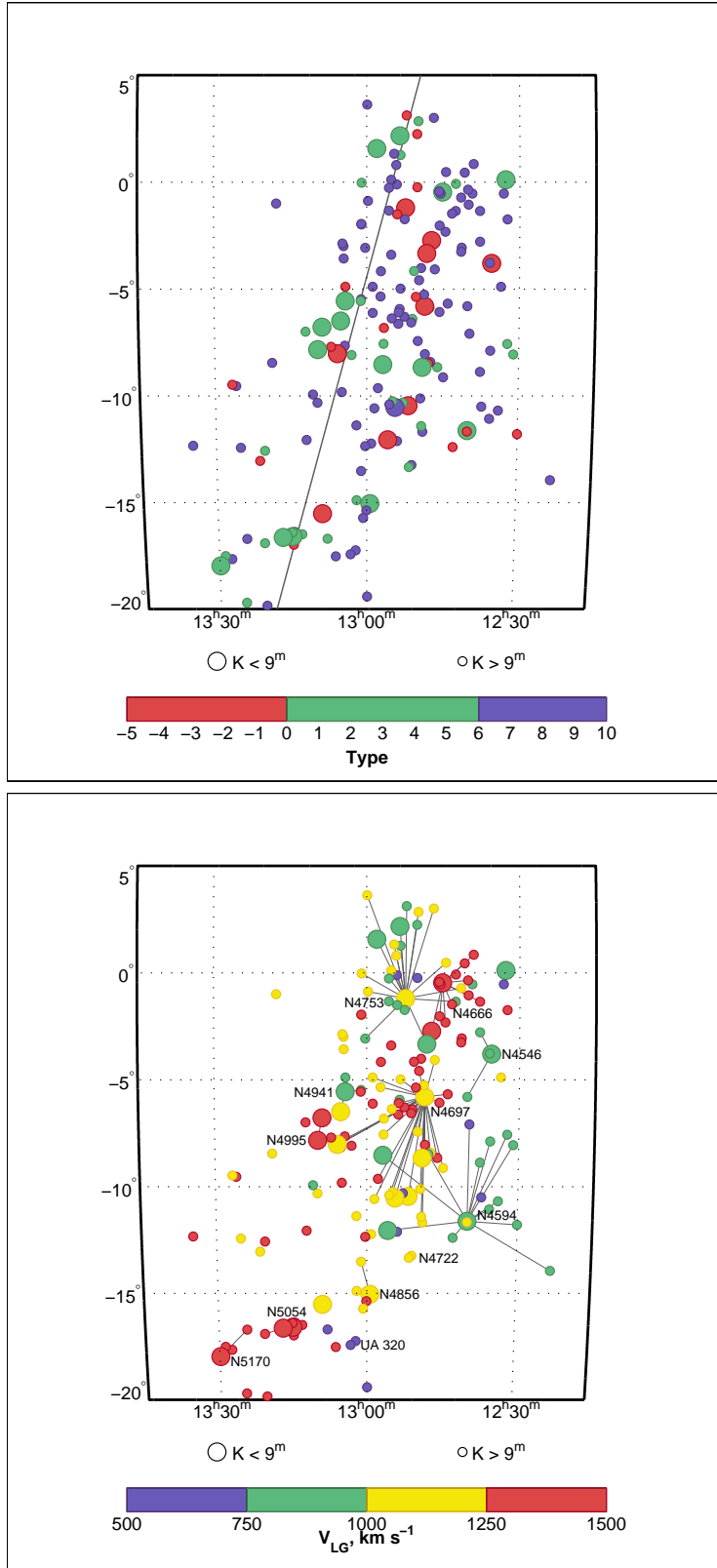


Figure 1. The Virgo Southern Extension complex of galaxies in equatorial coordinates. *Top:* early type, intermediate type and late type galaxies indicated by different colours. Bright ($K < 9^{\text{m}}$) galaxies are shown by larger circles. *Bottom:* the same field with indication of radial velocities of the galaxies and their membership in different MK-groups.

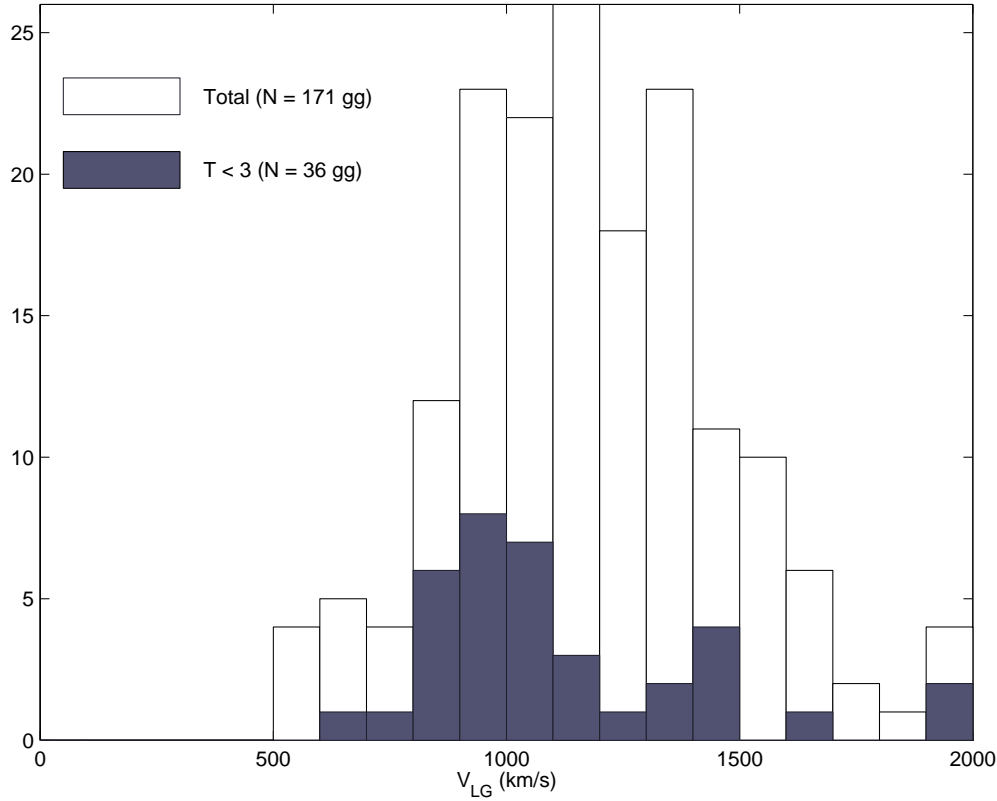


Figure 2. Distribution of galaxies in the Virgo SEEx region on their radial velocities in the Local Group frame. Galaxies with prominent bulges are shaded.

of different groups marked with circles are linked with dominating galaxies by straight lines. The triangles indicate 26 members of the NGC 4697 group which seems to be an artificial group (see Section 4 for details). The thick broken line demonstrates the behaviour of the running median with a window 1 Mpc.

Note some features of this diagram.

As a first approximation, both field galaxies and groups members follow the Hubble relation with the slope mentioned above (the H_0 parameter). About 90 % of all galaxies have distance estimates in the range from 8 to 25 Mpc. Taking into account the typical distance error of $\sim 20\%$, the length of the Virgo SEEx structure along the line of sight reaches about 15 Mpc which is twice more than its projected dimensions on the sky (7 Mpc). The mean distance to Virgo SEEx galaxies, 17 Mpc, is roughly the same that the distance to Virgo cluster centre, i.e. the Virgo SEEx filament is attached to the cluster at nearly right angle with respect to the line of sight. The behaviour of the running median indicates the presence of Z-shaped wave above the unperturbed Hubble flow with an amplitude of $\sim (200 - 300) \text{ km s}^{-1}$ that may be caused by a mass overdensity. As it can be seen from data by Tully & Shaya (1984) (see their Fig.4), the amplitude of Z-wave caused by infall of galaxies towards the

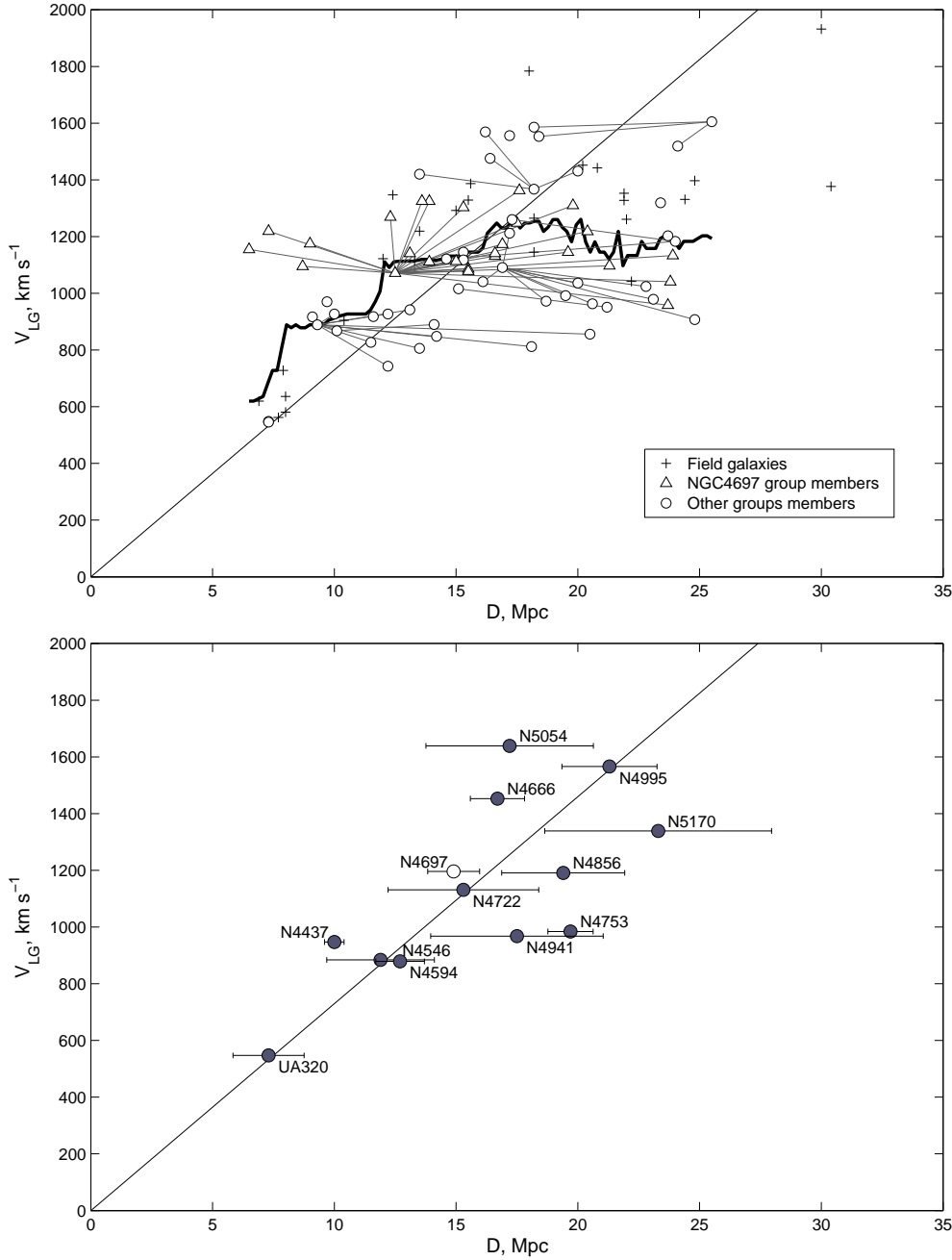


Figure 3. The velocity-distance relation for galaxies in the Virgo Southern Extension area. The undisturbed linear Hubble flow with $H_0 = 73 \text{ km s}^{-1} \text{Mpc}^{-1}$ is shown by the straight line. *Top:* individual galaxies; the solid polygon curve traces the running median on observational data with a window of 1 Mpc. *Bottom:* centres of the groups.

cluster mass $\sim 7 \cdot 10^{14} M_\odot$ should be only $(30\text{--}90) \text{ km s}^{-1}$ at angular distances $21^\circ\text{--}26^\circ$ from the Virgo centre. Hence, the observed amplitude $\sim 250 \text{ km s}^{-1}$ may be due to the collapse of the Virgo SEx complex itself. In the simplest model of the Hubble flow around point mass overdensity such amplitude corresponds to a mass of $\sim 6 \cdot 10^{13} M_\odot$.

The lower panel of Fig. 3 represents relation between mean distances and mean velocities for the centres of 13 groups. Each group is marked with a circle and labelled with the

name of its brightest galaxy. Distance error bars are marked by horizontal lines. As one can see, most groups in the Virgo SEx region follow the unperturbed Hubble flow with $H_0 = 73 \text{ km s}^{-1}\text{Mpc}^{-1}$ quite well within the error of galaxy distances. However, the NGC 4437 and NGC 4666 galaxy groups belonging to the foreground of the complex show signs of infall towards the complex centre. The NGC 4753 group demonstrates a significant effect of infall from the back side of the Virgo Southern Extension.

4 TOTAL MASS OF THE VIRGO SOUTHERN EXTENSION COMPLEX

The main characteristics of 13 groups in the considered region of sky according to Makarov & Karachentsev (2009, 2011) and Karachentsev & Makarov (2008) are presented in Table 2. The table columns contain: (1) name of the dominating galaxy, (2) equatorial coordinates of the group centre, (3) number of members with measured radial velocities, (4) mean radial velocity in the LG reference frame (km s^{-1}), (5) dispersion of radial velocities (km s^{-1}), (6) mean harmonic radius (kpc), (7) logarithmic total luminosity in the K_s -band in solar units, (8) logarithm of virial (projected) mass (in M_\odot), estimated as $M_p = \frac{32}{\pi G}(n - 3/2)^{-1} \sum_{i=1}^n V_i^2 R_i$, where V_i and R_i are radial velocity and projected distance of the i -th galaxy relative to the system centre (Heisler et al. 1985), (9) virial mass to K -luminosity ratio in solar units, (10) morphological type of the dominating galaxy, (11, 12) mean distance modulus and the group member modulus variance, (13) distance to the group centre (Mpc) corresponding to the mean modulus, (14) number of group members with measured distances. The initial mean parameters for these groups were slightly changed due to revised distances and appearance of new measurements of radial velocities.

It follows from the last column data of Table 1 that most galaxies in the considered area have distances estimated from Tully-Fisher relation (1977) with an accuracy of $\sim 20\%$ or $\sim 0.4^m$. All the groups in Table 2, besides the NGC 4697 group, have $(m - M)$ estimates dispersion of the same order: the rms value $\sigma(m - M)$ for the sample of groups is just 0.40^m . This result confirms the efficiency of algorithm used for selecting groups of galaxies (Makarov & Karachentsev 2011). The only exception is the NGC 4697 group. It presents a puzzle being characterised by small dispersion of radial velocities while the individual distance estimates of its members are spread widely from 7 to 24 Mpc. The galaxy grouping criterion (Makarov & Karachentsev 2011) uses radial velocities of galaxies as an estimator of their distances. In some regions of the sky where the velocity field is distorted by a local matter overdensity the

grouping algorithm is constrained as its application can result in selecting artificial groups containing field galaxies and members of their associations which are not physically bound. Supposedly NGC 4697 and other 35 galaxies with similar velocities compose probably such a kinematically spurious “pseudogroup”.

The total K -luminosity of galaxy groups forming the Virgo SEx complex reaches $1.7 \cdot 10^{12} L_{\odot}$ while field galaxies contribute only 10 % of this value. The sum of virial mass estimates for 13 groups from Table 2 amounts to $6.3 \cdot 10^{13} M_{\odot}$ which is practically similar to the estimate of the Virgo SEx total mass, $6 \cdot 10^{13} M_{\odot}$, obtained afore from the infall amplitude. This agreement between both total mass estimates for the Virgo SEx complex made from internal and external motions looks notable. The total mass to K -luminosity ratio of the complex is $37 \cdot M_{\odot}/L_{\odot}$. The global matter density $\Omega_m = 0.28$ in the Standard model with $H_0 = 73 \text{ km s}^{-1} \text{ Mpc}^{-1}$ (Fukugita & Peebles, 2004) and the mean K -band luminosity density $j_K = 4.3 \cdot 10^8 L_{\odot} \text{ Mpc}^{-3}$ (Jones et al. 2006) correspond to the ratio $M/L_K = 97 \cdot M_{\odot}/L_{\odot}$. Therefore, the obtained ratio of total mass-to-total K -luminosity, $37 \cdot M_{\odot}/L_{\odot}$, indicates the presence of a moderate amount of dark matter in the Virgo SEx complex with a typical value of $\Omega_m \simeq 0.11$.

According to data presented in Table 2, the NGC 4594 = M 104 = “Sombrero” group with mass-to-luminosity ratio $M/L_K = 38 \cdot M_{\odot}/L_{\odot}$ is among the most “dark” substructures in the Virgo SEx region. This group resides in the outskirts of the Local Volume and is populated with some faint dwarf galaxies of low surface brightness (Karachentsev et al. 2013), whose radial velocities and distances are not measured yet. Note, that almost all companions to Sombrero have distances, estimated via TF-relation, a bit higher than that of the Sombrero itself, estimated from surface brightness fluctuations (Tonry et al. 2001). A reason of this difference is not clear to us. It may be caused by an accidental error in the sbf- distance to Sombrero. Determination of accurate distance to it by the tip of red giant branch method with ACS HST would be a cardinal way to solve the problem.

5 CONCLUDING REMARKS

The Virgo Southern Extension, an extended complex of galaxies situated south of the Virgo cluster, seems to be one of the closest examples of cosmic filaments which appear commonly in N-body simulated large scale structure of the Universe. In the considered region of the sky given by $RA = [12^h 30^m - 13^h 30^m]$, $Dec = [0, -20^\circ]$ there are 171 galaxies with radial

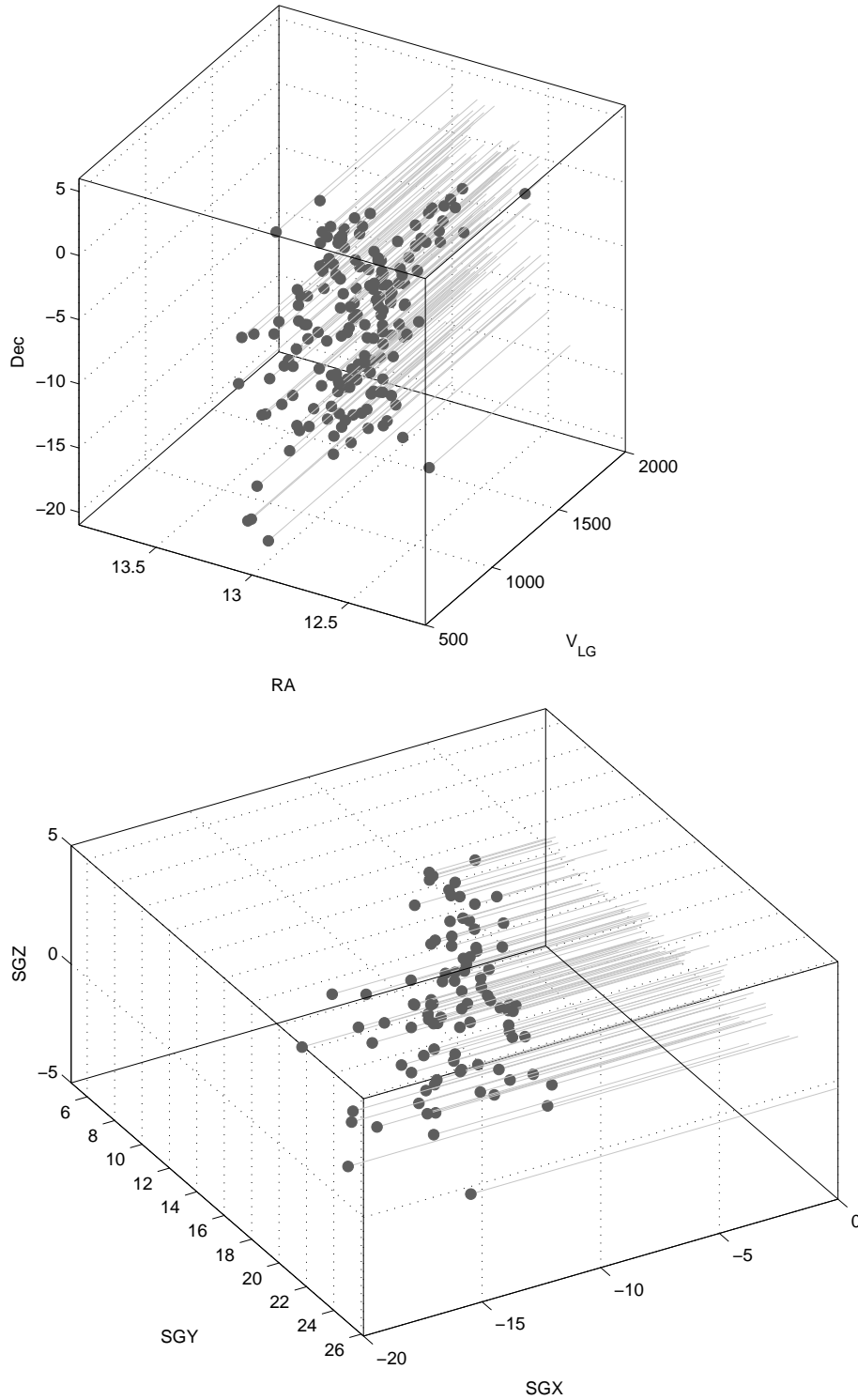


Figure 4. Overview of the Virgo SEx structure. *Top:* galaxies with measured radial velocities. *Bottom:* galaxies with individual distance estimates in Supergalactic coordinates.

velocities $V_{LG} < 2000 \text{ km s}^{-1}$, among them 98 galaxies have individual distance estimates. In Supergalactic coordinates the Virgo SEx structure is roughly characterized by dimensions of $\Delta SGX = 15$, $\Delta SGY = 7$ and $\Delta SGZ = 2$ Mpc where the major axis is directed along the line of sight, the second-major axis looks towards the Virgo cluster and the minor axis is

perpendicular to the Supergalactic plane (see Fig. 4). Hence, the Virgo SEx structure looks like a filament only in projection, having the true shape of a sheet.

Some authors claim that the Virgo SEx is somewhat like a cosmic feeding pipe conducting galaxies and intergalactic gas into the virialized core of the Virgo cluster (Tully & Shaya 1984, Yoon et al. 2012). Nevertheless, the mean radial velocity of Virgo SEx galaxies, $\langle V_{LG} \rangle = (1172 \pm 23) \text{ km s}^{-1}$, and their mean distance, $\langle D \rangle = (17 \pm 2) \text{ Mpc}$, are essentially the same as the corresponding values for the Virgo cluster itself. Taking this into account, the radial flow of matter towards the Virgo cluster could be hardly registered observationally.

About 80 % of galaxies populating the Virgo SEx region are members of the MK-groups (Makarov & Karachentsev 2011). The total K -luminosity of these groups amounts to $1.7 \cdot 10^{12} L_{\odot}$ while their total virial mass reaches $6.3 \cdot 10^{13} M_{\odot}$. As the mean K -band luminosity of stars matches their mean mass, the ratio of dark matter to visible (stellar) matter for the Virgo Southern Extension as a whole is $M_{DM}/M_{*} = 37$, i.e. a bit less than the corresponding value, 48 ± 6 , for the Virgo cluster (McLaughlin, 1999).

The velocity-distance diagram for 98 galaxies of the Virgo SEx area shows some signs of Z -shaped wave probably caused by the deceleration of the Hubble flow due to the Virgo SEx overdensity. The observed amplitude of this effect $\sim 250 \text{ km s}^{-1}$ corresponds to the overdensity mass of $\sim 6 \cdot 10^{13} M_{\odot}$ being in agreement with the sum of virial masses of 13 MK-groups found in this region.

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REFERENCES

- Abazajian K.N., Adelman-McCarthy J.K., Agueros M.A., et al. 2009, ApJS, 182, 54
- Binggeli B., Popescu C.C., Tammann G.A., 1993, A & A Suppl, 98, 275
- Chernin A.D., Teerikorpi P., Valtonen M. J., et al. 2012 A & A, 539, 4
- de Vaucouleurs G., de Vaucouleurs A., 1973, A & A, 28, 109
- Dietrich J.P., Werner N., Clowe D. et al. 2012, Nature (arXiv:1207.0809)
- Dinshaw, N., Weymann, R. J., Impey, C. D., et al. 1997, ApJ, 491, 45
- Fukugita M., Peebles P.J.E., 2004, ApJ, 616, 643

- Heisler J., Tremaine S., Bahcall J.N., 1985, ApJ, 298, 8
- Impey C.D., Petry C.E., Flint K.P., 1999, ApJ, 524, 536
- Jarrett T.N., Chester T., Cutri R. et al. 2000, AJ, 119, 2498
- Jones D.H., Peterson B.A., Colless M., Daunders W., 2006, MNRAS, 369, 25
- Karachentsev I.D., Makarov D.I., Kaisina E.I., 2013, AJ (submitted)
- Karachentsev I.D., Nasonova O.G., Courtois H.M., 2012, MNRAS (accepted; arXiv:1211.5975)
- Karachentsev I.D., 2012, Astrophys. Bull., 67, 123
- Karachentsev I.D., Nasonova O.G., Courtois H.M., 2011, ApJ, 743, 123
- Karachentsev I.D., Nasonova O.G., 2010, MNRAS, 405, 1075
- Karachentsev I.D., Makarov D.I., 2008, Astrophys. Bulletin, 63, 299
- Lauberts A., Valentijn E.A., 1985, Photographic photometry of 16000 galaxies on ESO blue and red survey plates, Springer-Verlag
- McLaughlin D.E., 1999, ApJ, 512, L9
- Magtesian A., 1988, Astrofizika, 28, 150
- Makarov D.I., Karachentsev I.D., 2011, MNRAS, 412, 2498
- Makarov D.I., Karachentsev I.D., 2009, Astrophys. Bulletin, 64, 24
- Masaki S., Fukugita M., Yoshida N., 2011, (arXiv:1105.3005)
- Mei S., et al., 2007, ApJ, 655, 144
- Meyer M.J., Zwaan M.A., Webster R.L. et al., 2004, MNRAS, 350, 1195
- Rosenberg J.L., Ganguly R., Giroux M.L., Stoke J.T., 2003, ApJ, 591, 677
- Spergel D.N. et al. 2007, ApJS, 170, 377
- Springob C.M., Masters K.L., Haynes M.P. et al. 2009, ApJS, 172, 599
- Tavio H., Cuesta A.J., Prada F. et al., 2008 (arXiv:0807.3027)
- Tonry J.L., Dressler A., Blakeslee J.P., et al. 2001, ApJ, 546, 681
- Tully R.B., Rizzi L., Shaya E.J., et al. 2009, AJ, 138, 323
- Tully R.B., 1987, ApJ, 321, 280
- Tully R.B., Shaya E.J., 1984, ApJ, 281, 31
- Tully R.B., 1982, ApJ, 257, 389
- Tully R.B., Fisher R.J., 1977, A & A, 54, 661
- Vennik J., 1984, Tartu Astron. Obs. Publ., 73, 1
- Yoon J.H., Putman M.E., Thom C. et al. 2012 (arXiv:1204.631)
- Zwaan M.A., Staveley-Smith L., Koribalski B.S. et al., 2003, AJ, 125, 2842
- Zwicky F., Herzog E., Wild P., Karpowich M., 1961-1968, Catalogue of Galaxies and Cluster of Galaxies, Pasadena, California Institute of Technology

Table 1: List of galaxies in the Virgo SEx region

Galaxy	RA (j2000) Dec.	V_{LG}	T	m_K	group	$m-M$	D	note
UGCA 278	122310.3–135645	942	10	13.6	NGC4594	30.58	13.1	tf
2MASX ...	123001.8–114731	909	–0	13.3	NGC4594	–	–	
CGCG014-054	123103.8+014033	954	9	13.2	NGC4437	29.91	9.6	tf
NGC4487	123104.5–080314	848	6	9.3	NGC4594	30.77	14.2	tf

Galaxy	RA (j2000) Dec.	V_{LG}	T	m_K	group	$m-M$	D	note
NGC4504	123217.5–073348	812	6	9.5	NGC4594	31.29	18.1	tf
UM 504	123223.6–014424	1883	9	13.8		—	—	
NGC4437 = N4517	123245.6+000654	970	6	7.3	NGC4437	29.94	9.7	tf
KDG155	123308.0–003159	581	10	14.0		—	—	
UGCA 286	123337.0–045306	1115	8	10.9		30.62	13.3	tf
UGCA 287	123355.2–104048	856	8	11.3	NGC4594	31.56	20.5	tf
NGC4546	123529.5–034735	890	–3	7.4	NGC4546	30.74	14.1	sbf
UGCA 289	123537.5–075240	806	8	11.1	NGC4594	30.65	13.5	tf
PGC0970397	123539.4–110402	927	10	13.2	NGC4594	30.01	10.0	tf
CGCG 014-074	123551.0–034558	829	9	12.5	NGC4546	—	—	
[KKS2000] 29	123714.1–102951	562	10	14.1		29.45	7.7	tf
[KKS2000] 30	123735.9–085202	917	10	14.8	NGC4594	29.79	9.1	tf
LCRS B...	123746.5–024654	947	9	13.7	NGC4546	—	—	
CGCG 014-080	123748.3–012042	1377	9	13.5	NGC4666	—	—	
SDSS ...	123902.5+005059	1436	9	12.2	NGC4666	—	—	
NGC4592	123918.7–003155	918	8	10.2	NGC4437	30.17	11.6	tf
HIPASSJ1239-07	123944.5–070514	743	10	15.1	NGC4594	30.44	12.2	tf
NGC4594	123959.4–113723	889	1	4.9	NGC4594	29.85	9.3	sbf
SDSS ...	124002.8–010300	1423	10	13.3	NGC4666	—	—	
SUCD1	124003.1–114004	1097	–1	14.7	NGC4594	—	—	
SDSS ...	124008.9–002101	1546	10	13.1	NGC4666	—	—	
NGC4597	124012.9–054757	868	8	11.7	NGC4546	30.01	10.1	tf
SDSS ...	124048.5+002655	1616	9	15.3	NGC4666	—	—	
CGCG 014-104	124122.9–030329	1292	8	11.4		30.89	15.0	tf
FGC 1485	124128.9–031513	1642	8	14.6		—	—	
SDSS ...	124129.2–004311	1027	9	15.9	NGC4753	—	—	
NGC4629	124232.7–012102	963	9	11.8	NGC4753	31.56	20.6	tf
NGC4632	124232.8–000447	1569	6	9.4	NGC4666	31.06	16.2	tf
MCG-02-32-26	124248.9–122326	828	–1	11.4	NGC4594	—	—	
SHOC 381	124318.5–012803	1529	8	14.9	NGC4666	—	—	
DDO 142	124403.5–054034	1259	8	11.7	NGC4697	—	—	

Galaxy	RA (j2000) Dec.	V_{LG}	T	m_K	group	$m-M$	D	note
UGC07911	124428.8+002805	1041	9	12.3	NGC4753	31.03	16.1	tf
UGC07913	124433.2−021909	1431	10	13.6	NGC4666	31.51	20.0	tf
VLA ...	124445.6−002536	1225	10	16.2	NGC4666	—	—	
UGCA 295	124454.1−090731	1194	8	11.6	NGC4697	—	—	
NGC4666	124508.7−002743	1367	5	7.0	NGC4666	31.28	18.2	tf
NGC4668	124532.0−003209	1476	7	10.6	NGC4666	31.07	16.4	tf
DDO 146	124541.4−060408	1303	9	11.8	NGC4697	30.92	15.3	tf
SDSS ...	124541.6−020151	1423	10	13.6	NGC4666	—	—	
SDSS ...	124547.9−002556	1507	9	14.0	NGC4666	—	—	
NGC4674	124603.5−083920	1325	1	10.3	NGC4697	—	—	
KDG 198	124637.5−040433	1111	10	14.3	NGC4697	30.71	13.9	tf
PGC043108	124649.3+030023	1069	10	13.0	NGC4753	—	—	
NGC4684	124717.5−024340	1420	−1	8.4	NGC4666	30.65	13.5	sbf
PGC1004122	124724.9−082431	1041	9	13.8	NGC4697	31.89	23.8	tf
MCG-01-33-007	124738.2−055203	1170	1	11.2	NGC4697	—	—	
PGC1003283	124750.9−082816	860	−1	12.1	NGC4594	—	—	
NGC4691	124813.6−031958	954	0	8.5	NGC4753	—	—	
HIPASSJ1248-08	124830.6−080232	1325	9	12.5	NGC4697	30.71	13.9	tf
NGC4697	124835.9−054803	1071	−5	6.4	NGC4697	30.49	12.5	sbf
DDO 148	124843.1−051514	1175	10	12.5	NGC4697	29.77	9.0	tf
LCRS B...	124854.2−114035	1145	9	12.8	NGC4697	31.46	19.6	tf
NGC4699	124902.2−083953	1218	3	6.5	NGC4697	31.55	20.4	tf
NGC4700	124908.2−112435	1219	5	9.8	NGC4697	29.06	7.3	tf
DDO 149	124918.3−040059	1353	8	12.4		31.70	21.9	tf
MCG-02-33-015	124923.7−100706	1131	7	11.4	NGC4697	31.10	16.6	tf
NGC4678	124941.9−043447	1269	8	12.5	NGC4697	30.46	12.3	tf
UGC07982	124950.2+025110	1024	4	10.2	NGC4753	31.79	22.8	tf
PGC1019240	124955.9−072527	1236	7	12.2	NGC4697	—	—	
MGC 0038179	125004.7−001357	608	−1	17.1		—	—	
KDG206	125007.3+021452	934	−5	13.2	NGC4753	—	—	
IC 0825	125019.2−052147	1367	−0	12.9	NGC4697	—	—	

Galaxy	RA (j2000) Dec.	V_{LG}	T	m_K	group	$m-M$	D	note
NGC4720	125042.8–040921	1452	2	10.8		31.53	20.2	tf
NGC4731	125101.1–062335	1325	6	9.8	NGC4697	30.66	13.6	tf
NGC4723	125102.9–131412	1145	9	12.4	NGC4722	30.93	15.3	tf
NGC4731A	125113.3–063329	1327	10	11.5	NGC4697	—	—	
NGC4722	125132.4–131948	1118	3	9.4	NGC4722	30.92	15.3	tf
NGC4742	125148.0–102717	1086	–5	8.4	NGC4697	30.95	15.5	sb
SDSS ...	125208.9+030715	900	–1	15.2	NGC4753	—	—	
NGC4753	125222.1–011159	1091	–1	6.7	NGC4753	31.08	16.9	SN
SDSS ...	125233.8–014349	983	9	12.9	NGC4753	—	—	
DDO 152	125236.3–061720	1363	8	12.8	NGC4697	31.23	17.6	tf
NGC4757	125250.1–101837	664	3	10.3		—	—	
NGC4771	125321.2+011609	992	6	9.0	NGC4753	31.45	19.5	tf
UGCA 305	125321.4–045841	1248	10	11.9	NGC4697	31.21	17.5	tf
NGC4772	125329.2+021006	907	1	8.3	NGC4753	31.97	24.8	tf
[KKS2000]38	125331.6–055540	905	10	14.0		30.09	10.4	tf
[KKS2000]39	125341.8–060502	1303	10	14.2	NGC4697	—	—	
NGC4775	125345.7–063720	1398	7	9.2	NGC4697	—	—	
UGCA 307	125357.5–120631	636	9	11.8		29.50	8.0	tf
CGCG 015-033	125401.9–013030	985	–1	12.0	NGC4753	—	—	
SDSS ...	125405.2–000604	697	9	13.3	NGC4753	—	—	
CGCG 015-035	125412.6+004809	1033	9	13.7	NGC4753	—	—	
NGC4781	125423.7–103214	1078	7	8.6	NGC4697	30.95	15.5	tf
SDSS ...	125437.7+011933	1061	9	15.0	NGC4753	—	—	
NGC4790	125451.9–101452	1173	5	9.8	NGC4697	31.14	16.9	tf
PGC0158179	125503.7–062210	1141	8	13.2	NGC4697	30.59	13.1	tf
2dFGRS...	125510.8–032351	1329	10	14.4		30.95	15.5	tf
UGC08041	125512.7+000700	1212	7	12.0	NGC4753	31.17	17.2	tf
UGCA 308	125531.0–102353	1141	10	13.3	NGC4697	31.10	16.6	tf
2MASX ...	125537.4–011948	760	9	13.6		—	—	
UGC08048	125539.4–001549	972	8	10.9	NGC4753	31.35	18.7	tf
NGC4802	125549.6–120319	827	–2	8.5	NGC4594	30.31	11.5	sb

Galaxy	RA (j2000) Dec.	V_{LG}	T	m_K	group	$m-M$	D	note
NGC4813	125636.1–064904	1206	–2	9.9	NGC4697	–	–	
IC3908	125640.4–073340	1133	5	9.1	NGC4697	31.90	23.9	tf
NGC4818	125648.9–083131	927	2	7.9	NGC4594	30.43	12.2	tf
UGCA 310	125712.1–040932	1377	8	12.7		32.41	30.4	tf
MCG-01-33-059	125716.5–052045	1097	8	11.9	NGC4697	31.64	21.3	tf
UGCA 311	125746.8–093801	1310	7	10.1	NGC4697	31.49	19.8	tf
NGC4845	125801.2+013433	979	2	7.8	NGC4753	31.81	23.1	tf
MCG-02-33-075	125828.3–103437	1095	8	11.8	NGC4697	29.70	8.7	tf
MCG-01-33-061	125848.9–060646	1442	8	12.2		31.59	20.8	tf
APMUKS(BJ)...	125849.6–045319	1155	9	13.2	NGC4697	29.07	6.5	tf
UGCA 312	125906.8–121340	1122	8	12.4		30.39	12.0	tf
NGC4856	125921.3–150232	1183	1	7.4	NGC4856	31.89	24.0	tf
SDSS ...	125945.1–005217	1139	9	15.2	NGC4753	–	–	
SDSS ...	125952.4+033759	1006	9	15.7	NGC4753	–	–	
KK176	125956.3–192447	620	10	13.7		29.19	6.9	tf
MCG-02-33-082	130005.1–152155	1260	9	11.4	NGC4856	31.19	17.3	tf
UGCA 314	130017.0–122048	1397	8	11.3		31.97	24.8	tf
SDSS ...	130017.6–030359	921	9	13.4	NGC4753	–	–	
DDO 159	130043.5–154256	1189	10	13.4	NGC4856	–	–	
NGC4904	130058.7–000140	1036	6	9.5	NGC4753	31.50	20.0	tf
UGC08127 n1	130100.7–015834	1216	10	13.6		–	–	
UGC08127	130103.7–015712	1331	8	12.7		31.94	24.4	tf
APMUKS(BJ)...	130105.2–052821	936	9	13.8	NGC4941	–	–	
HIPASS1300-13B	130107.0–133106	1121	9	13.5	NGC4856	30.81	14.6	tf
MRK 1342	130110.9–053324	1497	1	11.3		–	–	
MCG-02-33-093	130203.3–145258	1203	5	11.0	NGC4856	31.88	23.7	tf
NGC4920	130204.1–112242	1145	9	11.6		31.30	18.2	tf
UGCA 319	130214.4–171415	548	10	11.6	UGCA 320	29.32	7.3	mem
NGC4928	130300.6–080506	1553	4	10.2	NGC4995	31.32	18.4	tf
UGCA 320	130316.7–172523	546	10	10.8	UGCA 320	29.32	7.3	tf
2MASX ...	130412.1–045328	765	–1	11.0		–	–	

Galaxy	RA (j2000) Dec.	V_{LG}	T	m_K	group	$m-M$	D	note
NGC4941	130413.1–053306	951	2	8.2	NGC4941	31.63	21.2	tf
NGC4942	130419.1–073858	1586	7	10.4	NGC4995	31.30	18.2	tf
UGCA 322	130431.2–033421	1219	8	11.7		30.65	13.5	tf
LCRS B...	130431.8–025917	1148	10	13.6	LCRS B13	—	—	
HIPASSJ1304-02	130446.6–025216	1122	10	14.3	LCRS B13	—	—	
NGC4948	130456.0–075652	1113	7	10.7	NGC4697	30.88	15.0	tf
PGC0986100	130456.1–094849	1288	9	13.7		—	—	
NGC4948A	130505.8–080941	1387	8	11.9		30.97	15.6	tf
NGC4951	130507.7–062938	1016	6	8.9	NGC4941	30.82	15.1	tf
DDO 163	130514.3–075321	958	7	10.5	NGC4697	31.87	23.7	tf
NGC4958	130548.9–080113	1058	−2	7.6	NGC4697	—	—	
DDO 164	130618.4–173053	1265	10	13.0		31.30	18.2	tf
PGC0158522	130701.7–074155	1449	−1	12.3		—	—	
MCG-03-34-002	130756.7–164121	728	3	12.5		29.49	7.9	tf
NGC4981	130848.7–064639	1519	4	8.5	NGC4995	31.90	24.1	tf
NGC4984	130857.2–153059	1070	−1	7.7		—	—	
NGC4995	130940.7–075000	1605	3	8.2	NGC4995	32.03	25.5	tf
UGCA 330	130947.5–101912	1042	7	10.0		31.73	22.2	tf
PGC0984591	131038.6–095554	996	10	14.0		—	—	
UGCA 332	131158.9–120349	1932	7	12.0		32.38	30.0	tf
IC4212	131203.0–065929	1328	6	10.2		31.70	21.9	tf
MCG-03-34-019	131305.5–162842	1778	3	10.5	NGC5054	—	—	
LEDA 083827	131431.2–162248	1311	10	12.7		—	—	
NGC5035	131449.2–162934	1993	−1	9.6	NGC5044	—	—	
PGC0083842	131449.8–165825	1994	−1	11.7	NGC5044	—	—	
NGC5037	131459.4–163525	1698	3	8.6	NGC5054	—	—	
2MASX ...	131504.1–162340	1643	1	12.2	NGC5054	—	—	
MCG-03-34-40	131656.2–163535	1953	7	12.6	NGC5044	—	—	
NGC5054	131658.5–163805	1556	4	7.6	NGC5054	31.18	17.2	tf
UM 559	131742.8–010001	1106	10	13.7		—	—	
DDO 171	131841.2–082647	1150	10	11.6		—	—	

Galaxy	RA (j2000) Dec.	V_{LG}	T	m_K	group	$m-M$	D	note
NGC5088	132020.2–123418	1261	4	10.1		31.71	22.0	tf
ESO576-037	132028.9–195032	1558	9	13.8	NGC5084	—	—	
MCG-03-34-054	132041.0–165402	1518	5	10.9	NGC5054	—	—	
NGC5099	132119.6–130232	1145	−5	12.0		—	—	
MCG-03-34-067	132416.2–164213	1307	7	12.3	NGC5170	—	—	
UGCA 353	132442.1–194150	1784	5	10.6		31.28	18.0	tf
HIPASSJ1325-12	132509.3–122544	1003	7	12.5		—	—	
HIPASSJ1326-09	132550.3–093209	1651	9	14.1		—	—	
PGC0990590	132636.6–092828	1063	−1	13.0		—	—	
6dF ...	132726.3–173918	1464	8	12.8	NGC5170	—	—	
MCG-03-34-082	132847.0–173044	1267	4	10.2	NGC5170	—	—	
NGC5170	132948.8–175759	1319	5	7.6	NGC5170	31.84	23.4	tf
KDG227	133439.7–121950	1347	8	12.2		30.47	12.4	tf

Table 2: MK-groups in the region of Virgo Southern Extension

Name	RA(J2000.0)Dec.	N_v	V_{LG}	σ_v	R_h	$lg L_K$	$lg M_\odot$	$\frac{M_\odot}{L_\odot}$	T_1	$< m-M >$	σ_{m-M}	D	n_D
N4437	123310.7+000446	3	947	23	290	10.40	11.61	16	9	30.01	0.12	10.0	3
N4546	123529.5−034735	4	884	34	91	10.52	11.73	16	−3	30.38	0.37	11.9	2
N4594	124112.5−112103	16	879	80	642	11.59	13.17	38	1	30.52	0.52	12.7	11
N4666	124518.9−005318	14	1453	98	251	11.20	12.86	46	5	31.11	0.28	16.7	5
N4722	125130.7−131929	2	1131	14	31	9.96	10.50	4	3	30.92	0.4	15.3	2
N4697	125148.6−074321	37	1196	107	506	11.59	13.23	44	−5	30.87	0.75	14.9	26
N4753	125326.6−001502	23	984	97	677	11.54	12.96	26	−2	31.47	0.30	19.7	10
N4856	125929.5−150142	5	1191	44	258	10.94	12.22	30	0	31.44	0.46	19.4	4
UA320	130256.5−172146	2	547	1	40	8.9	8.5	1	10	29.32	0.4	7.3	1
N4941	130413.1−053306	3	968	35	270	10.71	12.08	23	2	31.22	0.40	17.5	2
N4995	130831.2−072620	4	1566	33	420	11.00	11.91	8	3	31.64	0.33	21.3	4
N5054	131632.6−163759	5	1639	94	60	10.97	12.80	65	4	31.18	0.4	17.2	1

Name	RA(J2000.0)Dec.	N_v	V_{LG}	σ_v	R_h	$lg L_K$	$lg M_\odot$	$\frac{M_\odot}{L_\odot}$	T_1	$< m-M >$	σ_{m-M}	D	n_D
N5170	132938.8–175442	4	1339	75	290	11.05	12.62	35	5	31.84	0.4	23.3	1